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Abstract

This report describes the result of the partial seam controlled retracting injection point (CRIP) underground coal gasification (UCG) field experiment carried out at the Washington Irrigation and Development Company (WIDCO) Mine near Centralia, Washington, in the fall of 1983. The test was designed to take advantage of the high-wall geometry at the mine and was carried out near the site of the earlier (1981-1982) large-block experiments. The primary goals of the experiment were to test the CRIP concept and to further evaluate the site as a potential for the future development of UCG.

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During the active gasification phase, which lasted 30 days, 1400 m^3 (2000 tons) of coal were affected. The test utilized primarily steam and oxygen as the injected reactants through a slant injection well drilled to a depth of 274 m (900 ft), nominally 20 ft below the roof of the coal seam. Two production wells -- one slant and one vertical -- were also provided. Approximately one-third of the coal was gasified through the vertical production well; the other two-thirds was gasified through the slant well after the injection point was moved by means of a controlled burnout of the injection well liner (the CRIP maneuver).

Three distinct periods of gasification were observed. The initial period, in which the vertical production well was in use, yielded a typical dry-gas heating value of 219 kJ/mol (248 Btu/scf). This was followed by a period of considerably higher gas quality, 261 kJ/mol (296 Btu/scf), which resulted from the switch to the slant production well and the CRIP maneuver. The final period began when a large-scale underground roof fall occurred and the typical dry gas heating value dropped to 194 kJ/mol (220 Btu/scf).

Introduction

One attractive scheme for gasifying coal by underground coal gasification (UCG) utilizes the high wall left at the worked-out boundary of a surface mine. Access to the coal seam by means of the high wall eliminates some of the expensive preparatory drilling that is required when the coal seam is entirely underground and accessible only from the surface.

The Centralia partial seam CRIP[1] (PSC) experiment described herein was designed to take advantage of such a geometry in the WIDCO mine, near the site of the previous LBK (large-block test) series.[2] Another unique feature of the experiment was the use of the CRIP system. When the product gas heating value declines to an unacceptable level the injection point is retracted upstream along the horizontal injection well into a region of fresh coal, where a new burn is initiated.

The PSC experiment was designed with the horizontal injection well placed in the upper 6 m (20 ft) of the seam. This placement was chosen so that significant interaction with the roof could occur within the 30-day time limit that budgetary constraints had imposed on the experiment.

Although an injection well drilled along the dip in the coal seam is a necessary part of the CRIP concept, the position of the production well is not so constrained. The PSC experiment utilized a vertical production well that intersected the end of the injection well and a slant production well that crossed the injection well. The slant production well was included in the basic scheme for several reasons. First, in large-scale operation, there may be economic advantages for using a long, horizontal production well instead of many vertical wells. Thus, experience in producing through a horizontal well was desirable. Second, if underground pressure drops become important, it may be desirable for the production point to move automatically toward the coal face along with the retracting injection point. Finally, although not part of the CRIP concept, one can make arguments for improved performance for systems in which the gas is produced through a long channel in the coal seam. The slant production well was designed to slope downward through the overburden into the coal to reduce the possibility of product gas leakage caused by drying and shrinking the coal along the casing. The experimental plan called for the use of both the vertical and horizontal production wells.

The original experimental plan[3], illustrated in Fig. 1, called for a number of CRIP retractions to be performed using the slant production well during most of the test. However, because of difficulties in drilling the slant wells, the number of CRIP retractions had to to be reduced to one. Also, the vertical production well had to be used for a longer period of time than had been originally envisioned. The vertical production well was used for the first 12 days of the experiment, and the slant production well was used for the last 18 days.

The experiment was carried out jointly by Lawrence Livermore National Laboratory (LLNL) and the Washington Irrigation and Development Company, whose open-pit mine was the site of the experiment. Sandia National Laboratory and the Radian Corporation were also involved in aspects of burn and particulate monitoring. Sponsors included the Department of Energy, the Gas Research Institute, the Washington Water Power Company, and Pacific Power and Light.

Experimental Layout

The PSC experiment was located at the WIDCO mine in Lewis County, near the town of Centralia, in southwest Washington State. It was conducted in the Big Dirty coal seam, which is part of the Skookumchuck Formation of the Late Eocene age. This coal is a nominal 35-ft (11 m) -thick subbituminous seam with numerous fractures and several strata of shale, clay, and siltstone stringers and dips from southwest to northeast at an average angle of 13.5 deg. The seam was accessed by drilling injection and production wells from an exposed face and down dip to a location approximately 900 ft (∿61 m) from the face and 200 ft (275 m) from the surface. At this location, a vertical production well and numerous instrument wells were drilled to intersect the coal at various points.

GEOLOGY

The lithology at the site, as determined from coring and gamma logs, is similar to that of the large-block site.[2] The average coal proximate analysis was: 17.3% moisture, 20.8% ash, 34.4% volatile matter, and 27.5% fixed carbon. The sulfur content was 1.2%.

HYDROLOGY

Single-well hydrologic testing at the site was conducted in the fall and winter of 1982-1983 on a total of 8 exploration boreholes[4]. Three hydrostatigraphic zones were tested: overburden siltstone, carbonaceous shale above the coal, and the Big Dirty coal seam (upper 18 ft).

The permeability ranges of the three media in the vicinity of the burn zone were:

- o Siltstone - 0.6 - 5.4 md
- o Shale - 2.4 - 7.4 md
- o Coal - 3.2 - 38. md

WELL AND INSTRUMENT LAYOUT

The well layout is shown in Fig. 2. The downhole mud motors and standard rotary drilling techniques used for the slant wells produced unfavorable results. A standard rotary drill string, modified to use lightweight aluminum alloy drill collars that provided some degree of vertical control, proved to be the most successful method. However, difficulties with drilling control limited the length of the injection well within the coal seam and resulted in the auxiliary production well, PRD-2, becoming the primary production well for the first part of the experiment. The injection well was drilled 6-3/4 in. diam to a length of 900 ft (274 m) and reamed to 11-3/4 in. diam to 630 ft, and 7-5/8 in. diam casing was set to that point. A 5-1/2 in. diam stainless steel liner was run to 831 ft. Initially, the 1/2 in. diam stainless steel igniter tube was also run inside the liner to this point. The slant production well was drilled to cross the injection well, also at 6-3/4 in. diam, to a total length of 820 ft. The entire hole was reamed to 8-3/4 in. diam. The well was then reamed to 13-1/2 in. diam to 640 ft, and a 9-5/8 in. diam casing was run.

A number of instrument wells were provided to monitor burn progress during the vertical and slant production phases of the experiment. The instrument wells were located to map the progress of the initial burn and with minimal coverage for the second burn. The P-1 well, which was provided to dewater the channel and production well, proved useful during the experiment.

Each instrument well was equipped with thermocouples at staggered locations within the coal and overburden. Two of the instrument wells, I-3 and I-5, contained two sets of thermocouples. The second set was an inverted thermocouple string fielded by Sandia National Laboratory, Albuquerque. This set was to be used should an override burn develop (burning across the top of the coal seam). Because of transmitter problems in well I-3, only those inverted thermocouples in I-5 recorded data during the experiment.

In addition to thermocouple strings, most of the instrument wells contained a cable for time-domain reflectometry (TDR) measurements of undamaged cable length. The method provided useful information on the extent of roof-collapse activity independent of the thermocouple measurements.

A controlled source audio magneto telluric (CSAMT)[6] antenna array, installed and operated by Sandia National Laboratory, was used to monitor cavity growth during the burn.

SURFACE SAMPLING EQUIPMENT

The product flow was metered, and continuous sampling of the product gas was done by the computer-controlled data-acquisition system. Standard combustion gas analyzers were used, as well as an on-line mass spectrometer and a special tar sampler.

The tar sampler utilized a methylene chloride bath and a refluxing condenser to collect tar and water from the product. Post-experiment analysis of the collected liquid determined the quantity of tar and water in the sample, which allowed a tar-to-dry-gas ratio to be calculated.

Particulate and environmental pollutant measurements of the product were carried out by the Radian Corporation. This task was managed by WIDCO, with funding from the Electric Power Research Institute.

Gasification Chronology

The active phase of gasification lasted a total of 30 days. During this time approximately 1400 m^3 (2000 tons) of coal were affected, and 27 Mmols (940 tons) of oxygen were injected. Before the start of gasification on October 16, 1983, a five-day period of pregasification testing occurred. After active gasification terminated on November 14, the underground system continued to produce steam for four additional days. Figure 3 shows the major operational information and events. Times are reported in decimal day, with day zero corresponding to October 16, 1983, the ignition day. A total of 1382 m^3 of coal was affected, 461 m^3 in the first cavity and 921 m^3 in the second cavity.

MAJOR EVENTS

The coal was first ignited on October 16 at 11:25 a.m. (day 0.476). Pyrophoric silane gas was used to ignite a propane flame downhole, which, in turn, ignited the coal. The tip of the igniter was located at the end of the liner, at a total depth of 831 ft (253 m). This location was 15 ft (4.6 m) upstream of instrument well I-6 (Fig. 2).

During the initial phase, the system back pressure was held at about 425 kPa (62 psia). This was done in an attempt to limit the amount of water entering the underground system. At 2:40 p.m. on October 17 (day 1.61), soon after the transition to steam/oxygen, the pressure letdown valve plugged momentarily, allowing the back pressure to build to a point where the rupture disk on the long production line blew. This caused a rapid loss of pressure in the underground system, and the small burn was swamped by a sudden inflow and/or redistribution of water. At this time, material balances indicated only about 9 m^3 (14 tons) of coal had been affected.

The second ignition took place on October 19 at 9:10 a.m. (day 3.382). Again, ignition was obtained on the first attempt. Flows were increased and gasification continued, with production from the vertical production well (PRD-2) for the next eight days.

The transition of flow to slant production well (PRD-1) was completed on October 28 at 11:38 a.m. (day 12.485). The transition was accomplished by throttling the produced gas flow at the PRD-2 wellhead with the PRD-1 well left open. The switch took about two hours.

By this time, we had pulled the igniter 25 ft back from the initial ignition point, or at 806 ft total length (see Fig. 2). This put it inside the injection liner opposite well I-7 and at the point where the injection well emerged from a large clay stringer back into the coal.

On October 30, at 8:36 a.m. Pacific Standard Time (day 14.40), the CRIP maneuver was performed. Twenty-five minutes after ignition, the injection liner thermo- couples indicated that the liner had been melted at a position coincident with the position of the igniter. After the successful CRIP maneuver, the flow rate was again raised gradually over the course of several days until maximum planned rates were reached..

On November 7, at 6:40 a.m. (day 22.314), a major underground roof collapse occurred. The event was marked by a rapid reduction in the gas heating value, a loss of several instrument well thermocouples, and a TDR response in well I-7 showing a cable termination change from the top of the coal to 18 ft (5.5 m) above the coal.

By November 13, it was clear that continued operation in the current mode would yield little new information. Since the 30-day time limit for the experiment was near, we decided to attempt a final CRIP maneuver, although we suspected that the igniter was stuck at the last CRIP location. In addition, the igniter, had it moved, would be 2 ft (0.6 m) into the clay stringer below the main coal seam. We had little hope that a new cavity could be formed under such conditions. After several ignitions, we concluded that the igniter was stuck at the first CRIP position and that the apparent motion observed during attempts to withdraw the igniter to a new location was caused by stretching the stainless steel tubing. Thus, we abandoned the attempt and resumed full-flow operation.

Because of the length of time that low-flow conditions were required for this procedure, the gas heating value was near zero as the injection was restarted. After overnight operation, however, levels essentially the same as those before the CRIP attempt were reached. After the heating value had leveled out, we decided that no further information could be gained and turned off the injection at 2:41 p.m. on November 14 (day 29.654). This was consistent with the 30-day maximum duration originally planned for the experiment.

Experimental Results

Plots of the major process parameters over the course of the experiment are shown in Figs. 4 to 10. The six major events during the experiment are marked on the figures. They are:

(1) First shutdown caused by blowout of the rupture disk.

(2) Restart after first shutdown.

(3) Switch in production from PRD-2 well to PRD-1 well.

(4) CRIP ignition begun.

(5) Roof collapse event noted.

(6) Final ignition begun.

Figure 4 shows the total injection and total wet-product flow for the entire experiment, and Fig. 5 shows the corresponding system pressures measured at the injection and (active) production wellheads. The product gas composition on a dry, tar-free molar basis is shown in Figs. 6 and 7. The increase in CH_4 following the CRIP is shown clearly in the figures. The amount of H_2S in the product also shows a marked increase during the times roof interaction was indicated from thermocouple and TDR measurements.

A considerable contrast in sulfur content was present in the system. The high sulfur content of the top 2 ft of coal and overburden resulted in high H_2S periods during periods when interactions with the roof where high. Gas recovery based on argon (or nitrogen during air injection periods) in Fig. 8 shows a gradual decline in recovery followed by a leveling-off period. The product heat of combustion on a dry-tar-free basis is shown in Fig. 9. Another useful plot, the product heat of combustion divided by the moles of oxygen used in generating the gas is shows in Fig. 10. This figure shows the trend toward higher energy efficiency after the CRIP maneuver, as well as the rapid decline coinciding with the roof-collapse event.

Tables 1 through 4 are also provided to summarize the key operating and process parameters over the entire experiment and for three selected sub-periods. The sub-periods were chosen to highlight the steady state operation of the test over three selected times:

(1) Pre-CRIP production using the PRD-2 well.

(2) CRIP burn prior to the roof-collapse event.

(3) CRIP burn after the roof-collapse.

Table 1. Summary information for the entire period of active gasification (0.4760-29.6568).

Total time interval (days)	29.181
Product heat of combustion	
dry, tar-free (kJ/mol)	213.
(Btu/scf)	242.
Total flows (Mmols)	
Injection	69.25
Production	177.82
Total dry gas	
Production (Mmols)	79.54
Coal consumed - wet with ash	
(Mg)	1335.9
(With char accumulation Mg)	1923.0
(Gas-loss-corrected Mg)	1656.9
(Gas-loss-corrected with char Mg)	2385.2
Composition of product gas (vol %)	
Ar	0.0097
N_2	0.0493
O_2	0.0001
H_2	0.3416
CH_4	0.0553
CO	0.1751
CO_2	0.3442
C_2H_4	0.0016
C_2H_6	0.0034
C_6*	0.0021
H_{10}*	0.0029
H_2S	0.0147
Product gas mole ratios	
H_2O/dry	1.23
Tar/dry[a]	0.0026
Gas recovery (%)	83.3
Product heat of combustion	
per mole O_2 (kJ/mol)	794.

[a]Assumed for molecular weight 0.179 kg/mole.

*Hydrocarbons other than CH_4, C_2H_4 and C_2H_6 are expressed as equivalent C_6 and H_{10} species.

Table 2. Summary information for the steady-state pre-CRIP period using vertical production well PRD-2 (5.4931-12.3058).

Total time interval (days)	6.813
Product heat of combustion	
dry,tar-free (kJ/mol)	219.
(Btu/scf)	248.
Total flows (Mmols)	
Injection	21.84
Production	58.07
Total dry gas	
Production (Mmols)	22.97
Coal consumed - wet with ash	
(Mg)	390.9
(With char accumulation Mg)	490.6
(Gas-loss-corrected Mg)	475.7
(Gas-loss-corrected with char Mg)	597.0
Composition of dry product gas (vol %	
Ar	0.0101
N_2	0.0017
O_2	0.0000
H_2	0.3739
CH_4	0.0456
CO	0.2038
CO_2	0.3416
C_2H_4	0.0018
C_2H_6	0.0018
C_6*	0.0019
H_{10}*	0.0028
H_2S	0.0150
Product gas mole ratios	
H_2O/dry	1.53
Tar/dry	0.0022
Gas recovery (%)	82.4
Product heat of combustion	
per mole O_2 (kJ/mol)	812.

*Hydrocarbons other than CH_4, C_2H_4 and C_2H_6 are expressed as equivalent C_6 and H_{10} species.

Table 3. Summary information for the steady-state period after the CRIP maneuver and before the major roof collapse (19.5967 - 22.0059).

Total time interval (days)	2.409
Product heat of combustion	
dry, tar-free (kJ/mol)	261.
(Btu/scf)	296.
Total flows (Mmols)	
Injection	8.71
Production	22.11
Total dry gas	
Production (Mmols)	10.78
Coal consumed - wet with ash	
(Mg)	194.1
(With char accumulation Mg)	274.2
(Gas-loss-corrected Mg)	253.1
(Gas-loss-corrected with char Mg)	357.5
Composition of dry product gas (vol %)	
Ar	0.0075
N_2	0.0081
O_2	0.0000
H_2	0.3562
CH_4	0.0842
CO	0.2028
CO_2	0.3117
C_2H_4	0.0018
C_2H_6	0.0067
C_6*	0.0032
H_{10}*	0.0045
H_2S	0.0133
Product gas mole ratios	
H_2O/dry	1.05
Tar/dry	0.0034
Gas recovery (%)	76.9
Product heat of combustion	
per mole O_2 (kJ/mol)	1220.

*Hydrocarbons other than CH_4, C_2H_4 and C_2H_6 are expressed as equivalent C_6 and H_{10} species.

Table 4. Summary information for the steady-state period after both the CRIP maneuver and the major roof collapse (22.3947 - 27.2060).

Total time interval (days)	4.811
Product heat of combustion	
dry-tar-free (kJ/mol)	194.
(Btu/scf)	220.
Total flows (Mmols)	
Injection	15.76
Production	42.33
Total dry gas	
Production (Mmols)	18.15
Coal consumed - wet with ash	
(Mg)	312.5
(With char accumulation Mg)	550.8
(Gas-loss-corrected Mg)	355.0
(Gas-loss-corrected with char Mg)	625.8
Composition of dry product gas (vol %)	
Ar	0.0114
N_2	0.0324
O_2	0.0000
H_2	0.3202
CH_4	0.0529
CO	0.1503
CO_2	0.4037
C_2H_4	0.0013
C_2H_6	0.0028
C_6*	0.0015
H_{10}*	0.0021
H_2S	0.0215
Product gas mole ratios	
H_2O/dry	1.33
Tar/dry	0.0014
Gas recovery (%)	89.0
Product heat of combustion	
per mole O_2 (kJ/mol)	573.

*Hydrocarbons other than CH_4, C_2H_4 and C_2H_6 are expressed as equivalent C_6 and H_{10} species.

To aid in the comparison, the flow ramping phase and operational upset periods were purposely avoided for the sub-periods.

The time interval for each summary is shown in the heading of the tables. Reduced data requiring an estimate of the affected coal are reported on two bases. One base assumes no modified coal (char) was left underground; the other assumed that material balance constraints are used to estimate the amount of char remaining underground.

Discussion

The experiment achieved its primary goals. A 30-day burn was conducted, which consumed approximately 1400 m^3 (2000 tons) of coal. A successful CRIP maneuver was performed in which a new gasification burn cavity was developed. An extended period of production through a horizontal production well was demonstrated. The underground system was operated long enough to allow for a large amount of roof involvement. Although some operational difficulties revolving primarily around boiler and power failures were encountered, we do not believe these difficulties had a major influence on the course of the gasification.

The silane igniter worked well during three documented ignition sequences. One of these ignition sequences included the melting through of the injection well liner and the establishment of a new burn cavity (the CRIP maneuver). A last sequence of ignitions occurred in a mode in which no monitoring of ignition was possible, but we have no reason to believe that ignitions did not take place.

As observed in the LBK tests, the gasification was not influenced strongly by changes in most operating parameters. Changes in the pressure, flow rate, and steam/oxygen ratio, in particular, had almost no influence on mature system performance. However, flow rate was a factor early during the flow-ramping period, and it influenced the amount of particulate production throughout the entire experiment. Flow rates were limited by particulate production during early cavity development and initial use of the slant production well.

As was our experience during the Hoe Creek Field Experiments[7] in Wyoming, the performance of the system was influenced strongly by changes in geometry, both natural and those under our control. The most dramatic natural change occurred on day 22.3 when the major roof collapse resulted in a sudden and permanent loss of gas quality. The two most important changes in geometry made under our control were the CRIP maneuver and the switch from the vertical production well, PRD-2, to the slant production well, PRD-1. Both changes resulted in improved gas quality. The data indicate that the improvement due to the CRIP maneuver lasted until the roof collapsed while the improvement afforded by the switch to the slant production well was transitory in nature. Because the events occurred within two days of each other, however, the relative influences of the CRIP and the slant production well are not completely separable.

GAS LOSSES

Gas losses during the experiment were estimated using either argon or nitrogen. Tracer losses were 16.6%, which we estimate is also the gas-loss value. From this number we can calculate a more fundamental parameter, the lost-gas flow rate.

The lost-gas flow rate did not seem to correlate, as we had expected, with cavity size or a pressure driving force term such as $(P_i^2 - P_p^2)$, where P_i is some average system pressure and P_p is an average gas-sink pressure. Also, simple correlations of gas loss with the hydrostatic pressure in the seam were not evident. The data do show one fairly clear trend, however. The gas losses were lower when operation was shifted to the slant production well and continued to decline with continued operation in this mode. This seems to suggest, along with the lack of correlation of lost-gas rate with cavity size, that the leakage path was associated primarily with production from the PRD-2 well, and that the accumulation of water and rubble at the PRD-2 end of the system reduced the gas-loss flow when production was switched to PRD-1.

WATER INFLUX

Water influx is defined as water input to the system, from all sources. These include water intrusion into the burn and the drying of inert material. Note that this term does not measure the total amount of water that enters the underground system from the surrounding strata because water that enters the system and is not turned to steam and produced cannot be measured.

During the PSC test, as during our Hoe Creek experiments, we found pressure to be ineffectual in controlling water influx. Although no correlation of water influx with pressure was evident, the correlation of water influx and changes in system geometry was fairly strong. As with gas losses, the measured water influx decreased after operation switched to the slant production well. This reduction may have been a result of several factors. First, the PRD-2-related cavity may have served as a reservoir that drained water away from the active burn zone. Second, the primary source of water may have been associated with the PRD-2 end of the system, much like the primary gas-loss path. Finally, when the major roof collapse occurred on day 22.3, the water influx increased temporarily, but there was no lasting trend. This last point suggests that the increased inflow of water to the burn was not the major factor in reducing gas quality.

CAVITY GROWTH

Our estimation of cavity growth during the PSC experiment combines information from several sources: (1) thermocouple response data, (2) time-domain reflectometry (TDR) data, (3) Sandia's controlled source audio-magnetotelluric (CSAMT) surface monitoring of cavity growth (4) total coal consumption by means of material balance calculations, and (5) such peripheral data and events as H_2S levels in the product (indicating roof-interaction periods) and the sharp decline in process performance following the roof collapse.

On the basis of an analysis of the above data, we drew burn-cavity contours for various times during the experiment, as shown in Fig. 11. Each contour is consistent with the material balance results of total coal consumption. However, the conversion from consumed volume to plan-view area required that an assumption be made as to the depth of coal consumed in the affected region. For convenience, we simply assumed a coal depth based on the average height of the roof above the injection borehole, 4.3 m (14 ft). This assumption also represents a conservative estimate of the actual areal sweep. No attempt was made to draw the necked-down exit-flow channel, although one undoubtedly exists. However, the the amount of coal associated with this region is small, and the drawing of such a channel would be based solely on conjecture. We see from Fig. 7 that the hydrogen sulfide levels in the product increased steadily from day 4 through day 6 and then leveled out until the switch to the PRD-1 well. After the CRIP maneuver, the level of hydrogen sulfide again began to climb, reaching the previous high levels by day 20. Finally, the roof collapse on day 22 marked a dramatic increase in hydrogen sulfide for the remainder of the experiment. The above observations indicate roof-interaction transition periods occurred on days 6, 20 and 22.

A review of the data before and after days 6 and 20 shows that the roof interaction had little or no effect on several key processing parameters: (1) product heat of combustion, (2) heating value per mole of O_2 injected, (3) produced CO, CO_2, and CH_4 and (4) water influx. The only parameters to indicate a response seem to be C_2H_4, C_2H_6, and H_2S content in the product.

The transition period before and after day 22 is much different. All of the key processing parameters show a marked response to the roof collapse. In fact, its effect on the heating value and product composition is greater than we would have expected on the basis of the heating and drying of the overburden alone. Postulations are that the roof collapse altered the flow geometry of the UCG process in a manner that caused oxygen override and the subsequent consumption of a portion of the gasification products in a region remote from char or coal, causing the declines in process parameters.

The ability to predict early cavity growth and roof interaction on process performance is the goal of a multidimensional UCG process simulator (CAVSM) developed by LLNL following the LBK experiments. The model currently utilizes a constant roof growth rate of 3.0 ft per day based on results from the five LBK tests. It is interesting to note that the time required to reach the 13-ft overburden predicted by the model (4.3 days) agrees well with a 4.1-day estimate for the PSC experiment based on a firm H_2S response by day 6.2. The time to reach a 16-ft overburden for the CRIP cavity was calculated to be 5.3 days versus 5.6 days based on H_2S response. In addition to the roof growth rate, the model predicts only a small degradation in process performance following the initial roof contact. This degradation was also observed in the field results. At present, however, the model could neither predict the major roof-collapse event occurring on day 22 nor the proposed oxygen override effect of this event.

Conclusions

We have drawn the following conclusions on the basis of results from the PSC experiment.

- WIDCO coal is satisfactory for in-situ coal gasification. (The two distinct levels of gas quality seen were: a relatively high level after the CRIP maneuver and lower levels during the first cavity burn and after the large-scale roof collapse.
- The rate of cavity growth was fairly consistent with that observed during the LBK tests.
- The slant production well worked well and did not create large pressure drops in the system.
- The pressure drops were managable and, we believe, localized to an area near the injection point. Long-term changes in pressure drop/flow performance were not present; however, pressure drops were higher after the switch was made to the slant production well.
- No strong change in process parameters was seen as the roof was contacted initially.
- The CRIP system worked well and provided a valuable control mechanism.

- o The silane igniter worked satisfactorily, but improved engineering is needed for future applications.
- o The gas loses encountered during the experiment were relatively small, but are of potential concern.
- o The amount of water encountered during the experiment was a problem, and system pressure could not be used as an effective control measure. The water influx was reduced greatly when the flow was switched to the slant production well.
- o The steam/oxygen ratio, pressure, or flow rate had no lasting major effect on the gas quality. However, the major decreases in flow associated with low air flows and ignition sequences did cause a decrease in gas quality.
- o We believe that the large-scale roof collapse that occurred altered the flow geometry and, in turn, led to a rapid and sustained loss in gas quality.
- o Particulate production, although heavy occasionally, was low during steady operation at the maximum flows. The largest amounts of particulate produced were associated with the periods of increasing flow rate.
- o The underground system is forgiving and will tolerate frequent upsets (e.g., boiler and power failures) with no apparent long-term negative effects.

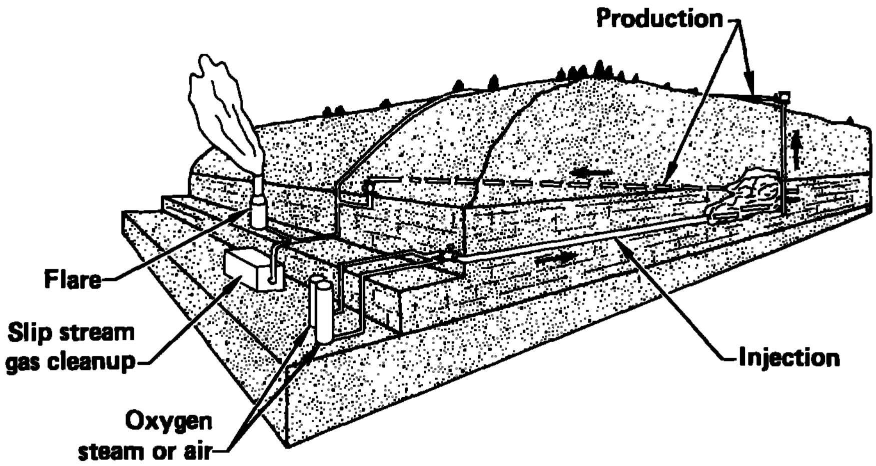


Figure 1. Planned layout of the Centralia partial seam CRIP test.

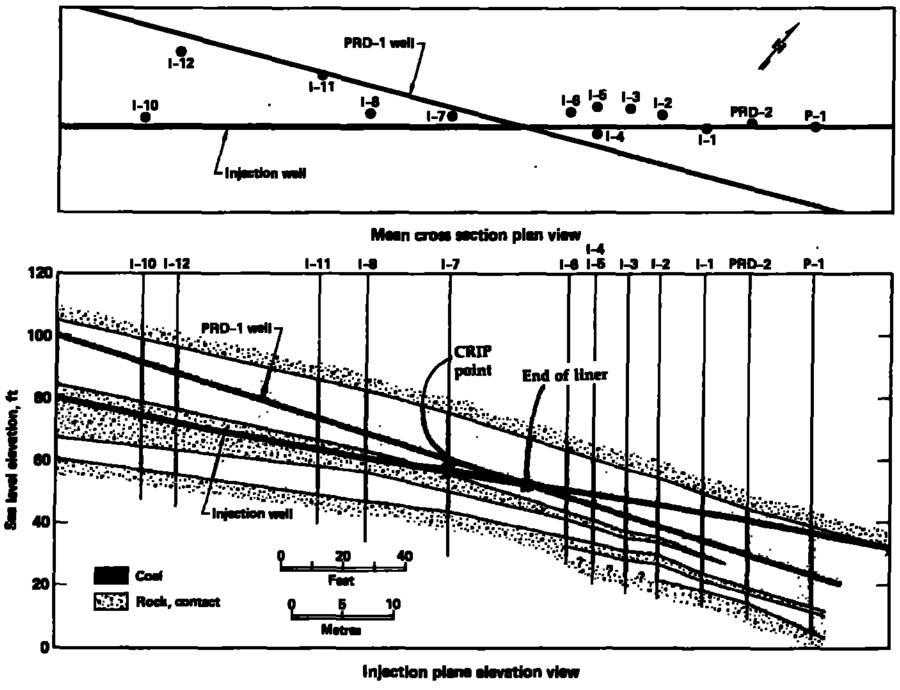


Figure 2. Plan and elevation views of process and instrument wells in the vicinity of the burn cavity. The locations of the initial and CRIP ignition points are indicated on the elevation view.

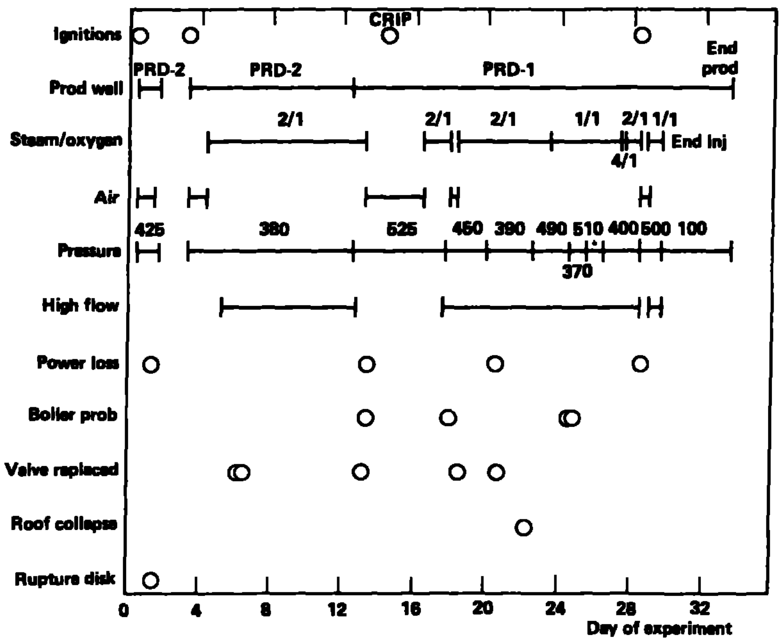


Figure 3. Summary of operating conditions and major events for the PSC experiment.

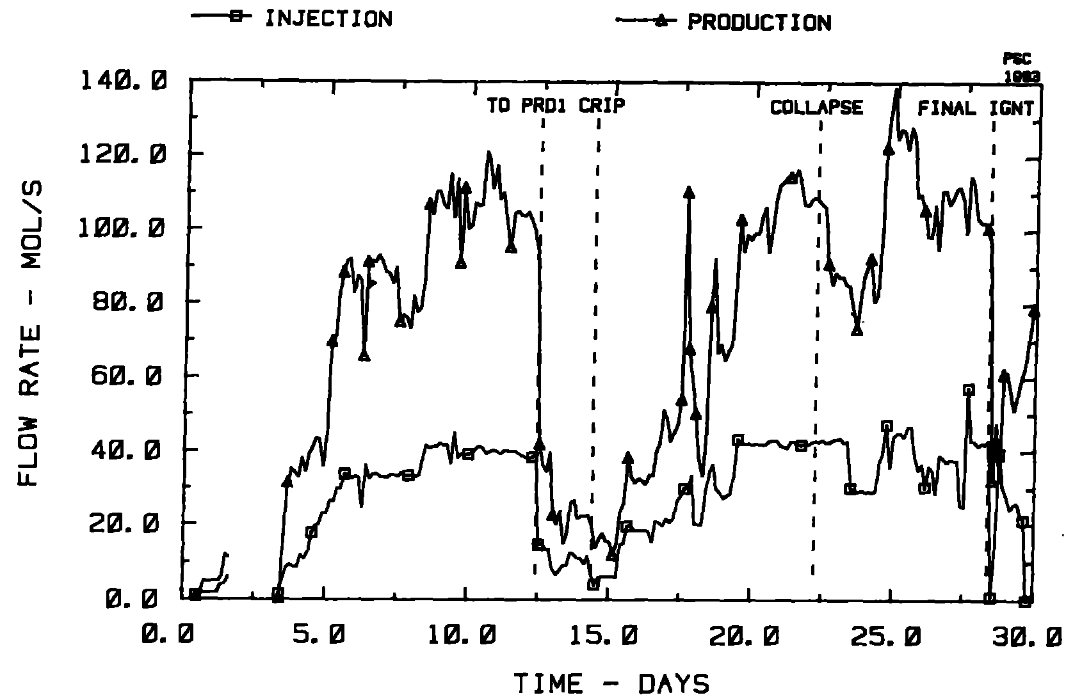


Figure 4. Injected and produced flows during the PSC experiment.

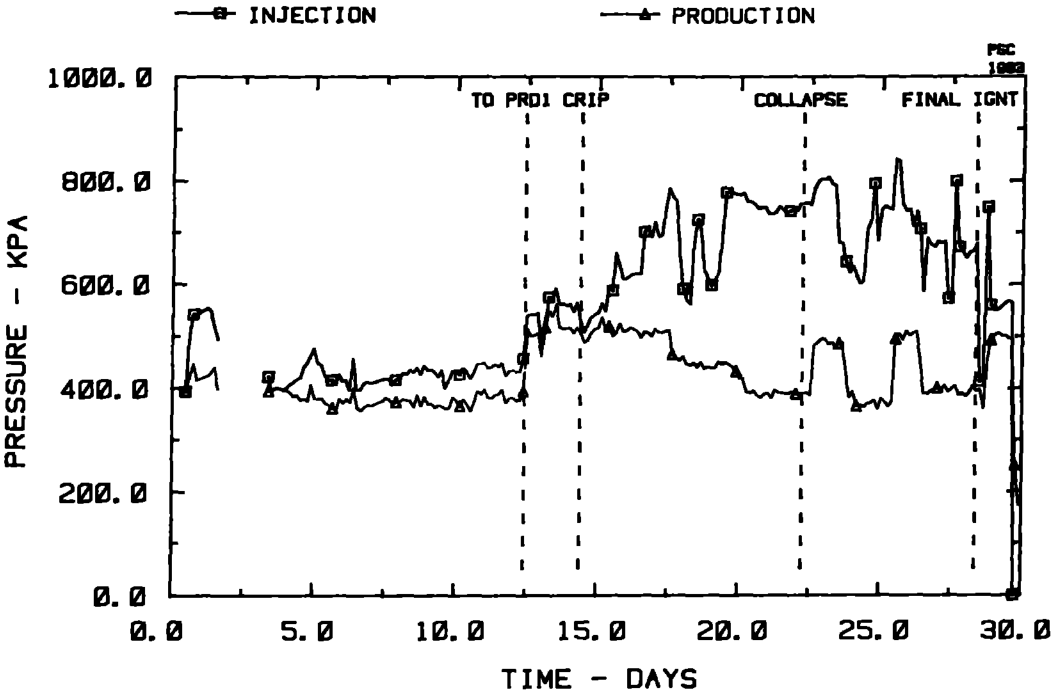


Figure 5. Injection and production well pressures during the PSC experiment.

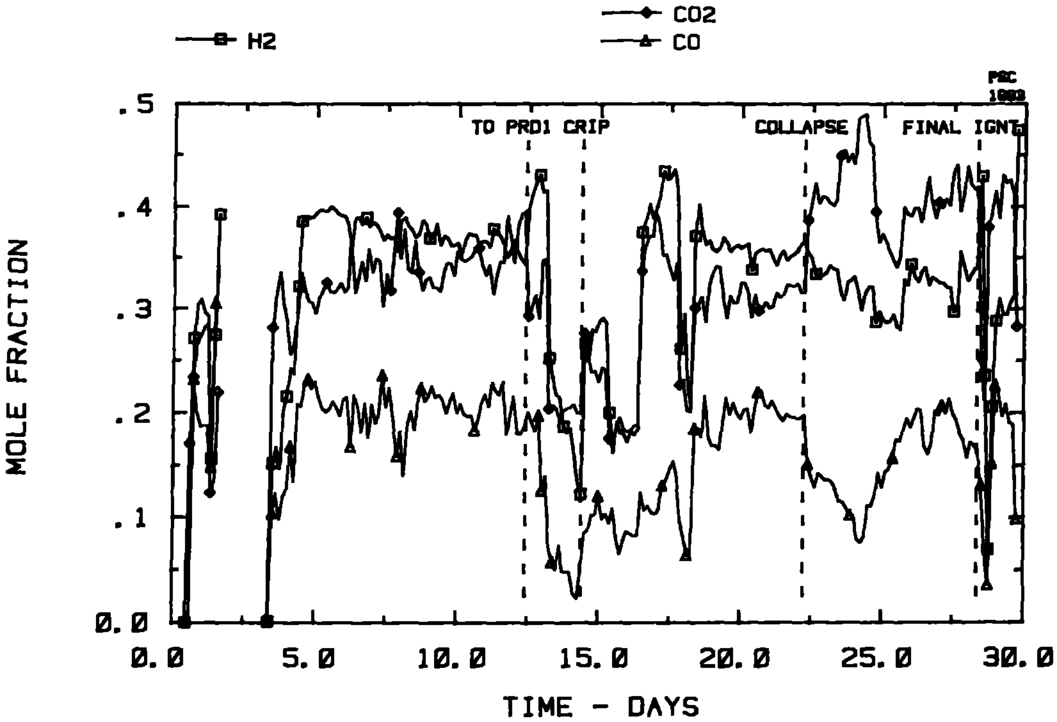


Figure 6. Produced gas mole fraction of hydrogen, carbon monoxide and carbon dioxide presented on a dry basis.

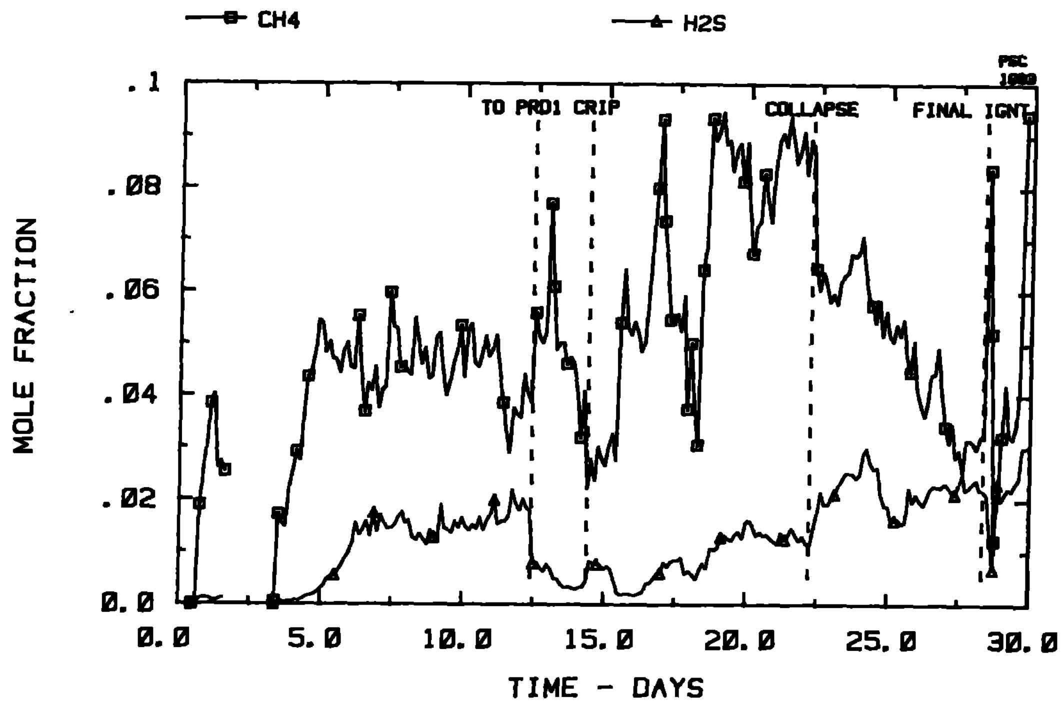


Figure 7. Produced gas mole fraction of methane and hydrogen sulfide presented on a dry basis.

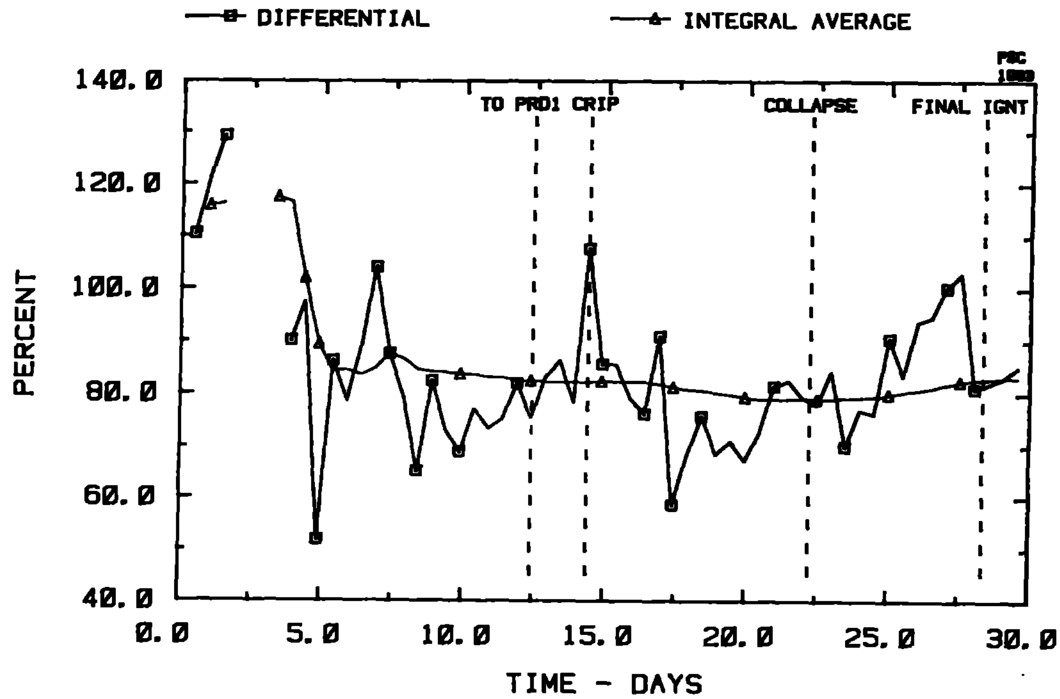


Figure 8. Instantaneous and integral values of computed gas recovery.

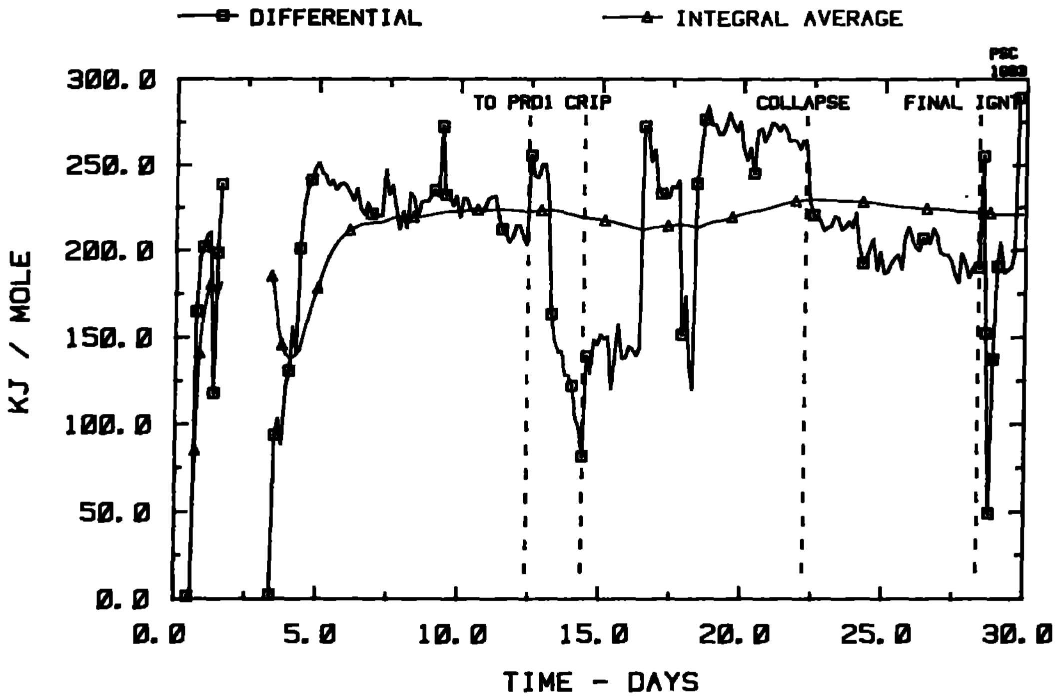


Figure 9. Instantaneous and flow-weighted running average of the dry gas heat of combustion.

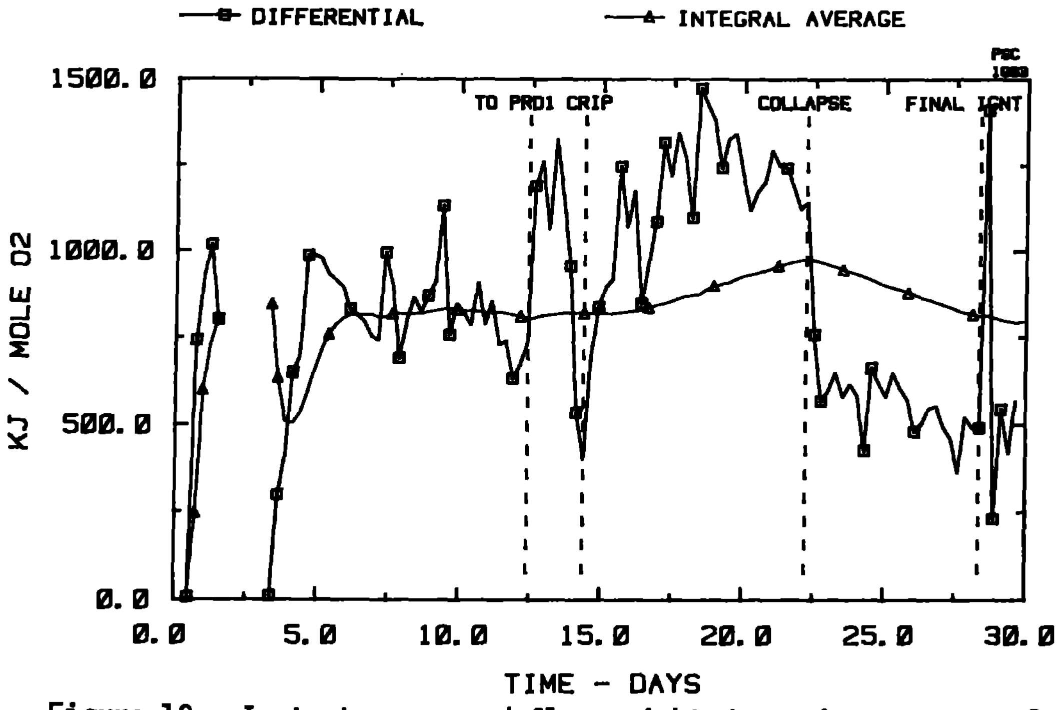
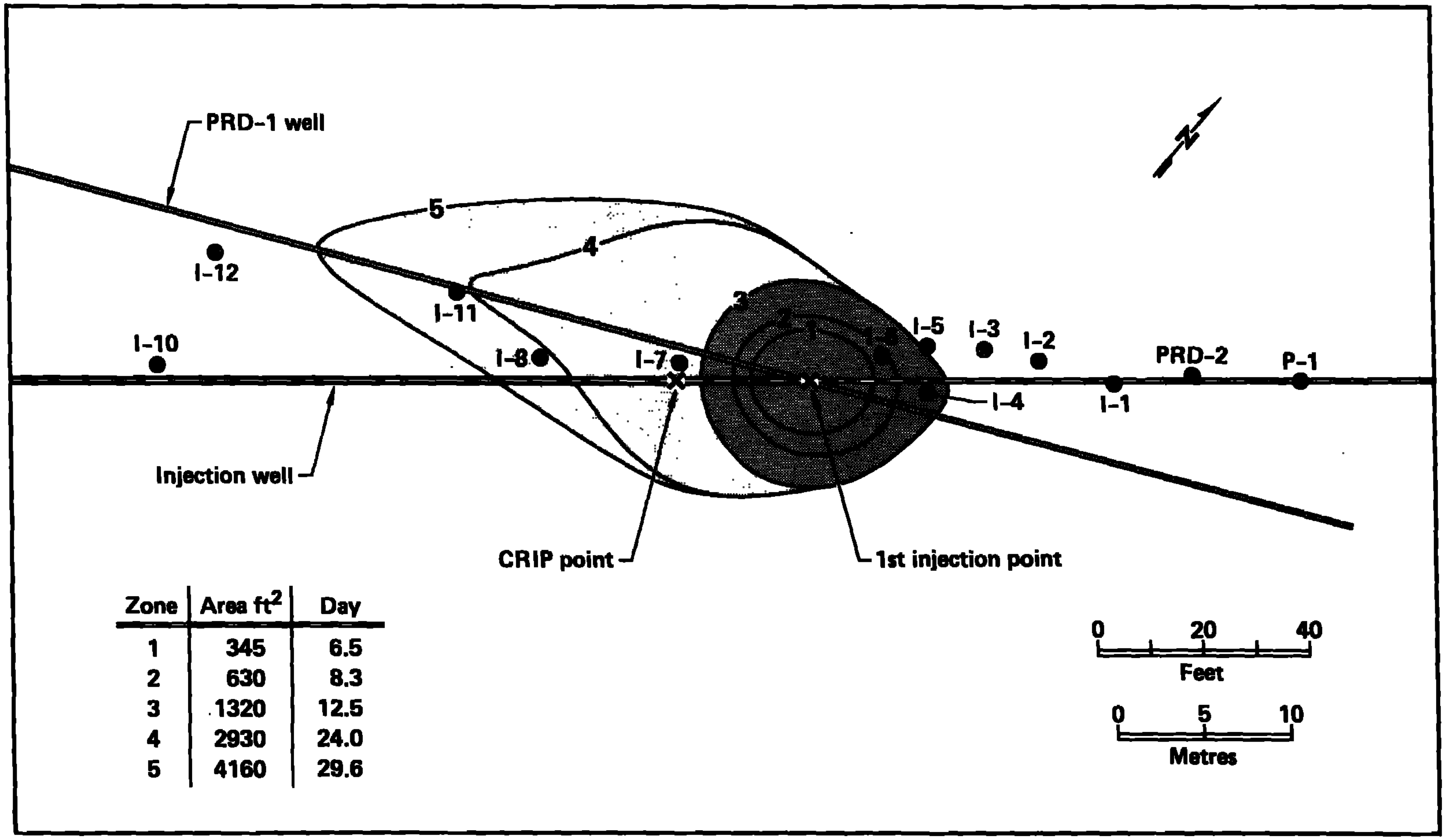


Figure 10. Instantaneous and flow-weighted running average of the heat of combustion of the produced gas per mole of oxygen consumed in generating the gas.



Mean cross section plan view

Figure 11. Approximate burn cavity contours at selected times during the PSC experiment.

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